Institute of High Energy Physics
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Beam background experiment at BESIII/BEPCII

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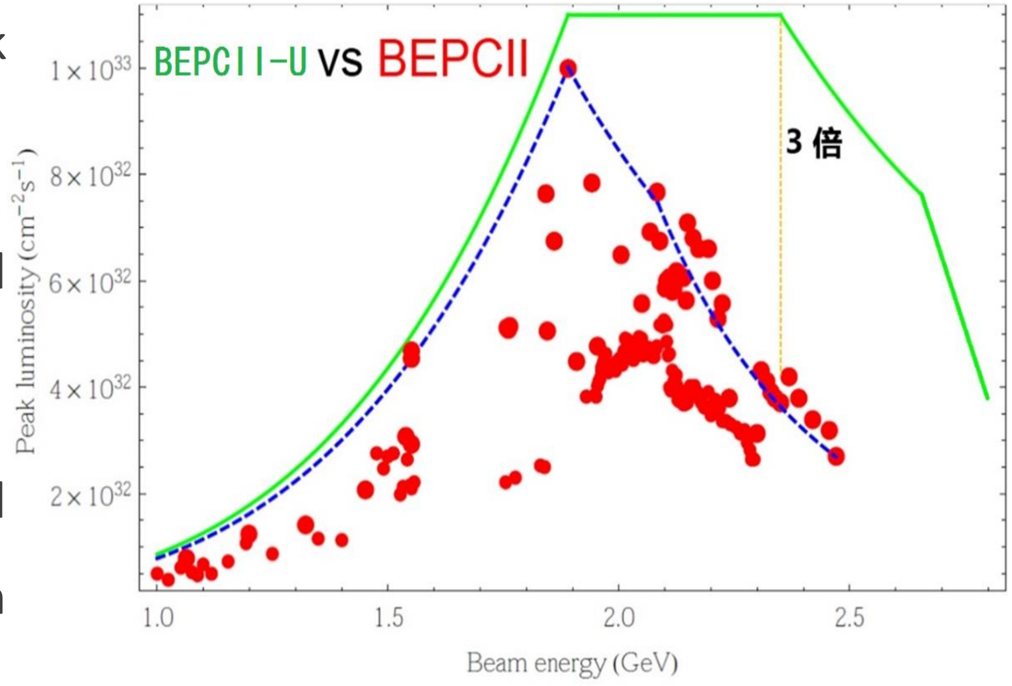
Motivation

- The BEPCII upgrade aims to extend the beam energy to 2.8 GeV and optimize the beam parameter at 2.35 GeV. The peak luminosity is expected to be $1.1 \times 10^{33} cm^{-1} s^{-1}$.
- The consequent high beam background should be controlled within a safety range.
- Precise beam background simulation and experimental confirmation are necessary for commissioning the beam background of BEPCII upgrade project.



Beam background experiment in 2021

- First beam background experiment in recent years.
- Plan to measure the Touschek background and beam-gas background separately.
- Compare the experimental results with the simulation results to optimize the background simulation program.

$$O_{\mathrm{SB}} = S_{\mathrm{tous}} \cdot \frac{I_t \cdot I_b}{\sigma_x \sigma_y \sigma_z} + S_{\mathrm{gas}} \cdot I_t \cdot P(I_t) + S_{\mathrm{const}},$$

- $\boldsymbol{O_{SB}}$ is the total single beam background rate that can be represented by count rate of the MDC, $\boldsymbol{I_t = n_{bunch} \times I_b}$, and $\boldsymbol{P(I_t)}$ is vacuum pressure.
- The constant background is measured without any beam in the storage ring.
- The Touschek and beam–gas backgrounds can be separated by using different bunch currents.

Beam background experiment in 2021

Touschek background: Parameters setting for bunch number scan

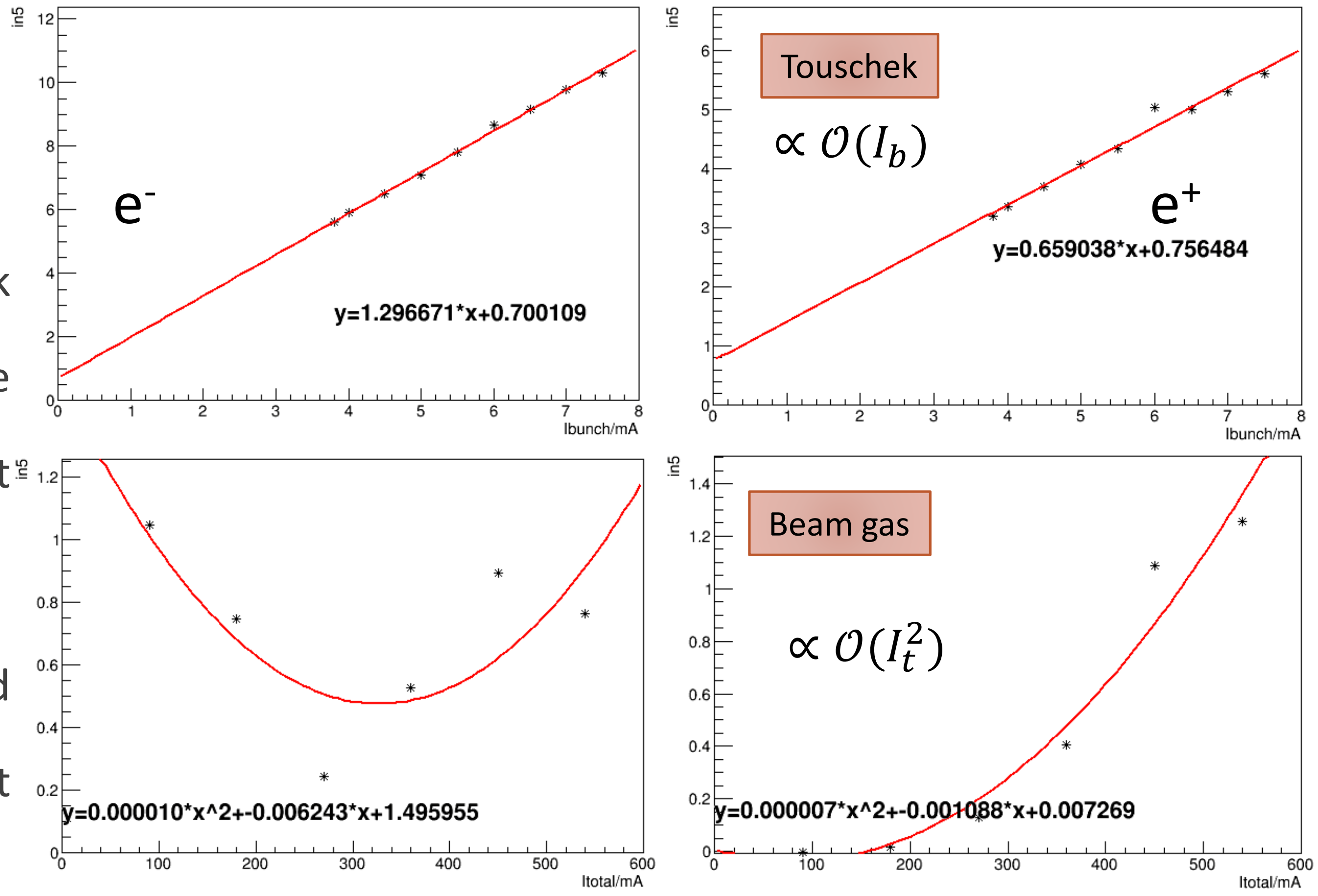
N bunch	118	113	100	90	82	69	64	60	56
I_b/mA	3.8	4.0	4.5	5.0	5.5	6.5	7.0	7.5	8.0

Beam-gas background: fixed bunch current to 6 mA and scan bunch number from 15 to 90.

Beam background experiment in 2021

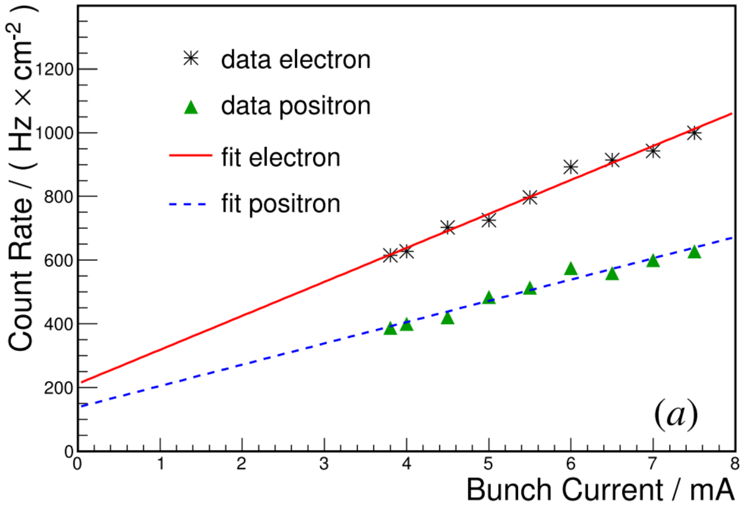
$$O_{\text{SB}} = S_{\text{tous}} \cdot \frac{I_t \cdot I_b}{\sigma_x \sigma_y \sigma_z} + S_{\text{gas}} \cdot I_t \cdot P(I_t) + S_{\text{const}},$$

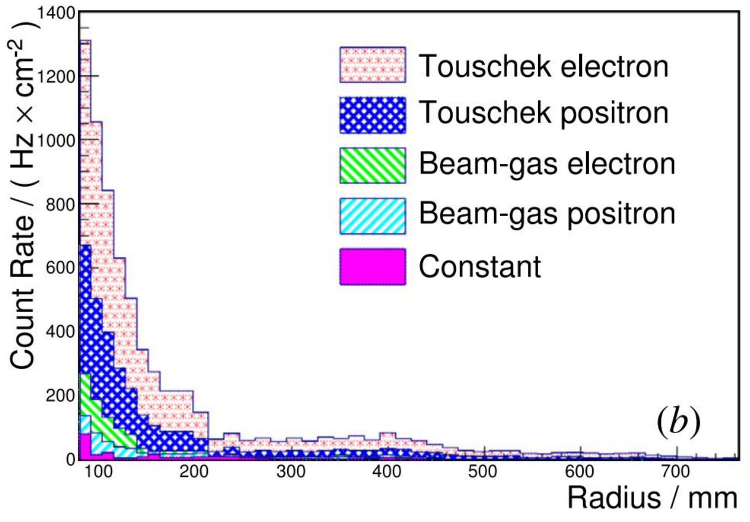
- The nominal total beam current is set to 450 mA;
- A clear linear is observed in the distributions of dark current (in_S5) with respect to the bunch current. The intercept of the fit includes beam–gas and constant background.
- The beam-gas background is so small that it is covered by fluctuations of the Touschek and constant backgrounds.



Beam background experiment in 2021

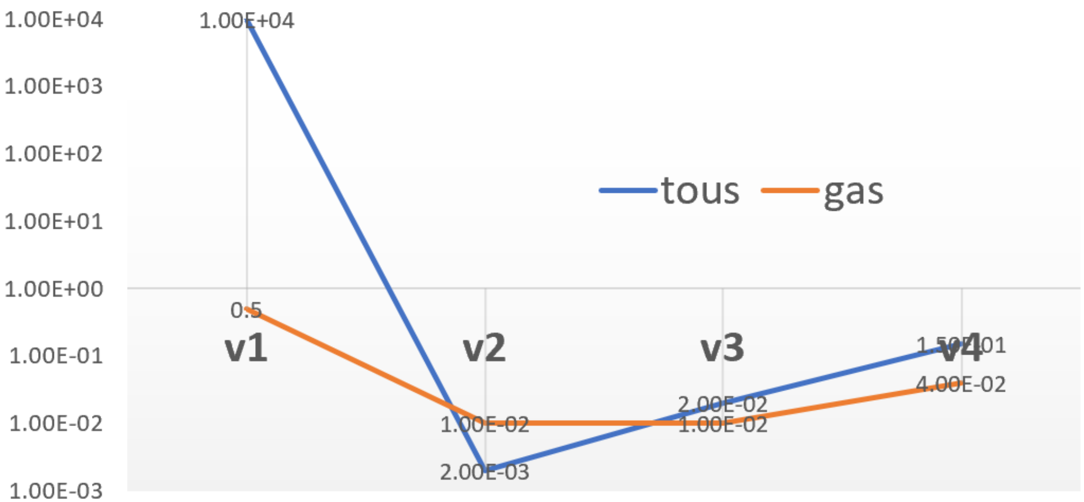
- The fit to the count rate in the first layer of the MDC with respect to the bunch current for both electron and positron beam.
- The accumulated count rate of separate background sources in all MDC layers when bunch current is 6 mA.
- The Touschek background is dominant in all layers and the beam–gas background occupies a small portion, especially in the outer layers.
- The background at first layer of MDC is composed of 75.1% Touschek, 15.4% beam-gas, and 9.5% constant background.





Simulation of beam background at BEPCII

- v1
  - Original version after experiment
- v2
  - Extend input particles to $\pm 10m$
- v3
  - Update MDI geometry with CAD file
- v4
  - Set radius of movable collimators from 19mm to 35mm



data/MC ratio at MDI layer1 to simulation versions for e⁻ beam

- ✓ By analyzing the experimental data, four versions of the beam background simulation program have been updated.
- ✓ The differences between the program and data are becoming increasingly smaller.

Simulation of beam background at BEPCII

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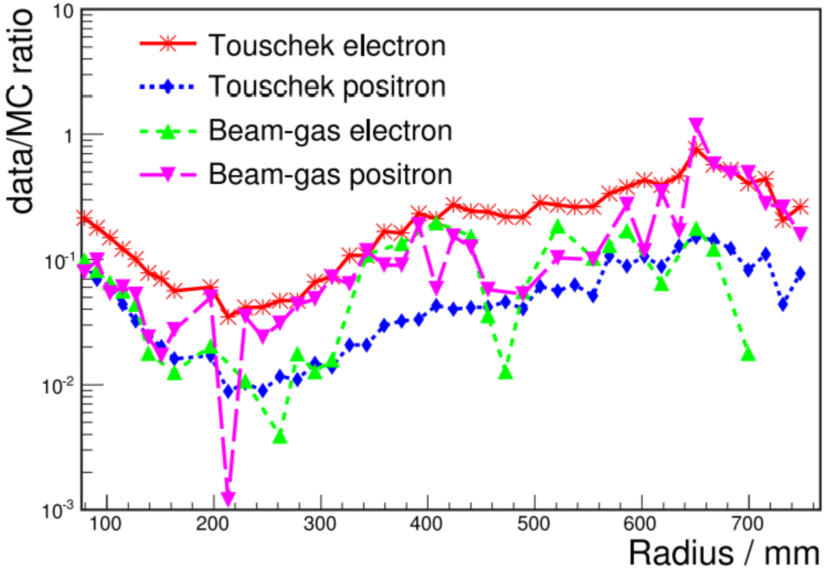
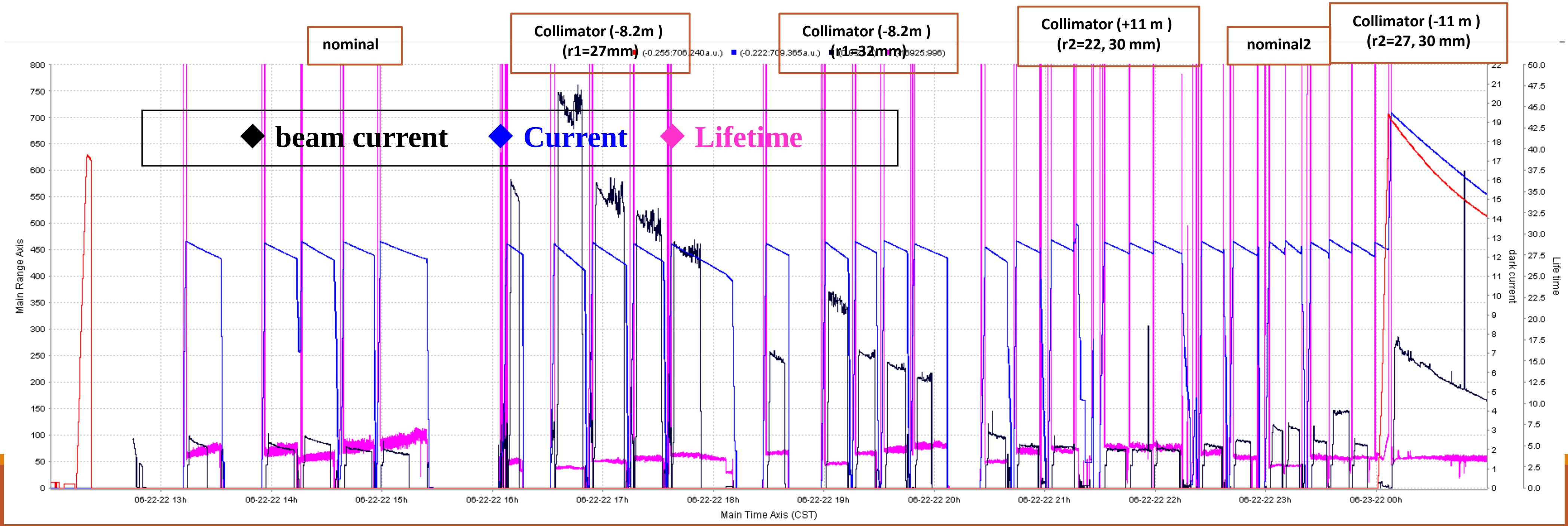


H.C. Shi*, B. Wang*, H.Y. Shi et al., Nuclear Inst. and Methods in Physics Research, A 1050 (2023) 168174

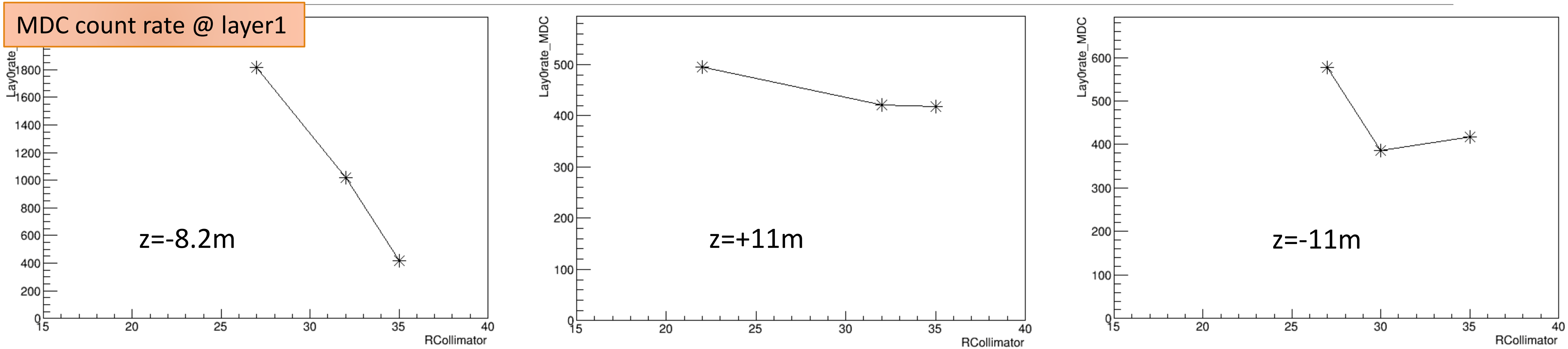
The results of the beam background simulation and experiment have been published in NIMA.

Beam background experiment in 2022

- The nominal beam current is 450 mA. Four bunch number (60, 75, 82, and 90) is selected.
- Changing the aperture of movable collimator located at -8.2 m from 35 mm to 32 mm (27 mm), the beam background increased more than four times. The injection is failed if the aperture is decreased to 22 mm.
- Adjusting the apertures of the other two movable collimators did not noticeably affect the beam background.



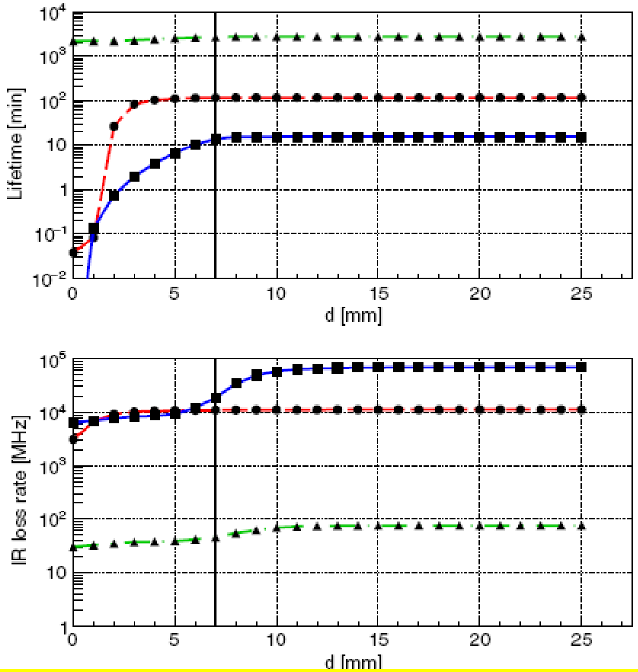
Beam background experiment in 2022



- First experiment of movable collimator in 10 years.
- Changing the aperture of movable collimator does not obviously affect the machine's operation.
- Experimental study on aperture of movable collimator and the beam background.
- Further study requires more experimental data.

Experiment plan in 2023

- The further movable collimator experiment is ongoing.
- Scan the dynamic aperture of collimators to observe the change of beam background.
- Consider more effects, such as close orbit distortion, life time, beam size, beam-beam effect, and so on.



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Summary and next to do

- Two rounds of beam background experiment are collected for optimizing the beam background simulation.

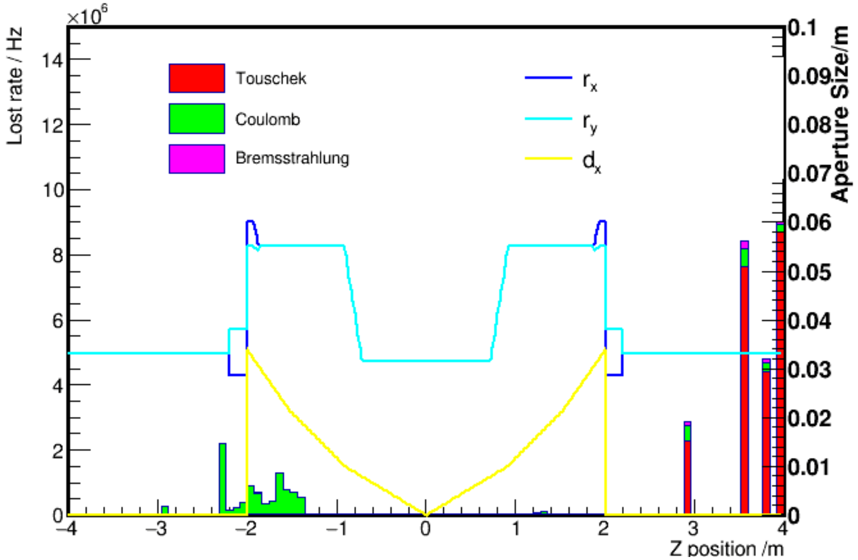
- The data/MC ratio shows that the Touschek background in simulation is larger than in the experiment by one to two orders of magnitude.

- More background experiments at BEPCII will be carried out to optimize the simulations.

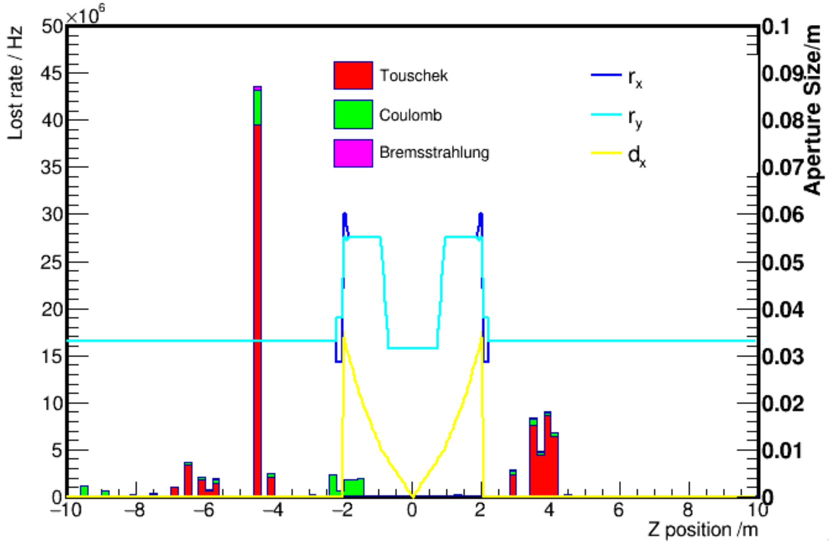
Backup

Simulation v1 -> v2

- Based on experimental data, it is necessary to extend the input particle range from $\pm$4m to $\pm$10m for Geant4 simulation. Due to betaX reaching its maximum value at $\pm$4.2m, most background particles are lost at this point.

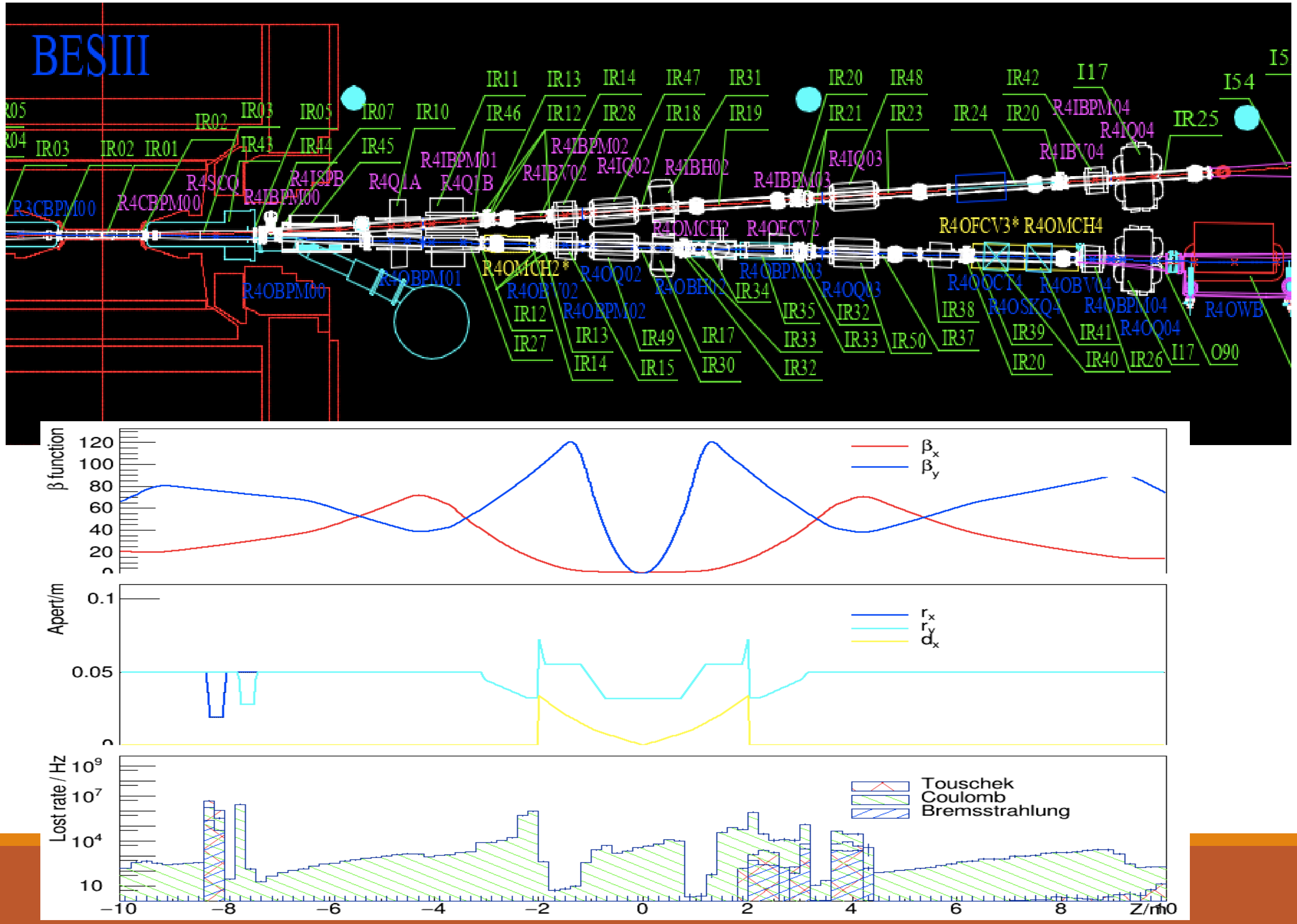


Lost particle in Z direction ($\pm 4m$)



Lost particle in Z direction ($\pm 10m$)

MDI geometry update v2->v3: SAD



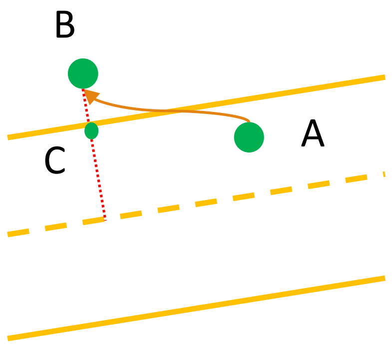
- 根据CAD设定SAD中的孔径
- 上游7.9m, 8.2m分别存在y,x方向的collimator
- 超过90%的粒子丢失在collimator处

v2->v3: SAD->G4坐标转换

为了充分模拟束流管内壁的粒子与束流管在Geant4中的相互作用，将SAD输出的粒子的xy方向位置固定在管壁上，z方向不变

会带来与z方向步长的同量级的误差(<20mm)

坐标转换需要与Geant4中孔径匹配，束流管中心轴位置是关键

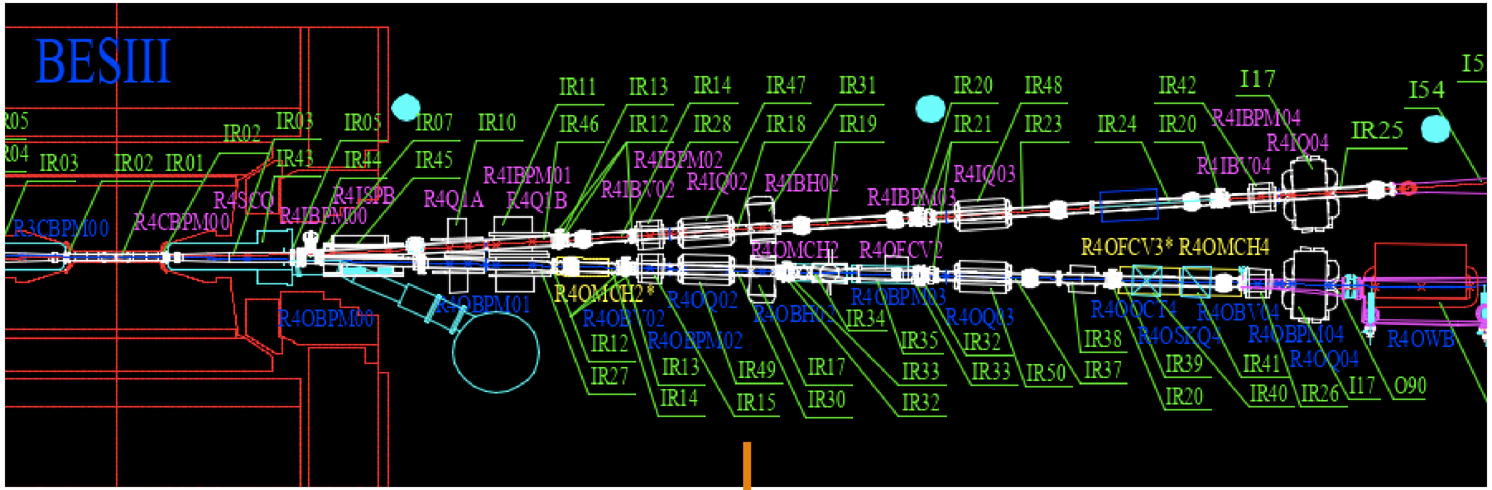


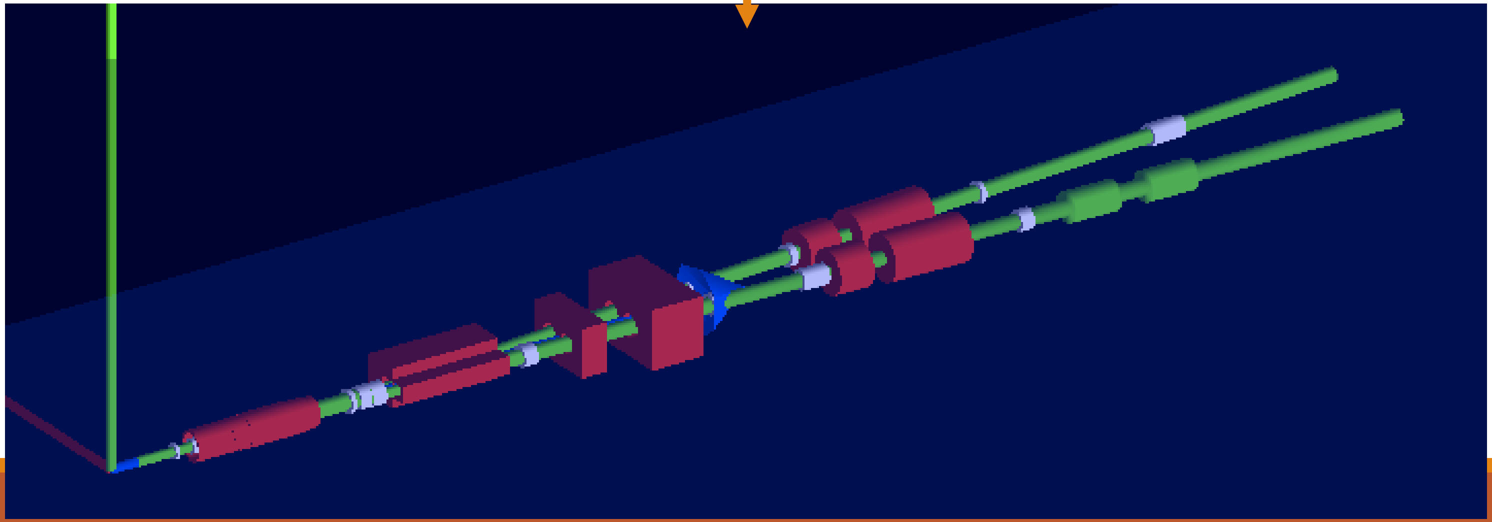
重建位置:C点

Z range/mm	X方向中心轴函数(mm)
(-2129,2129)	x=0
(-12000,-2129)	x=0.026*z+18.385
(2129,2300)	x=0.02655*z-19.237
(2300,2900)	x=0.045*z-61.638
(2900,12000)	x=0.0656*z-121.355

*CAD中，测量离IP的距离来测量截距

MDI geometry update v2->v3: Geant4



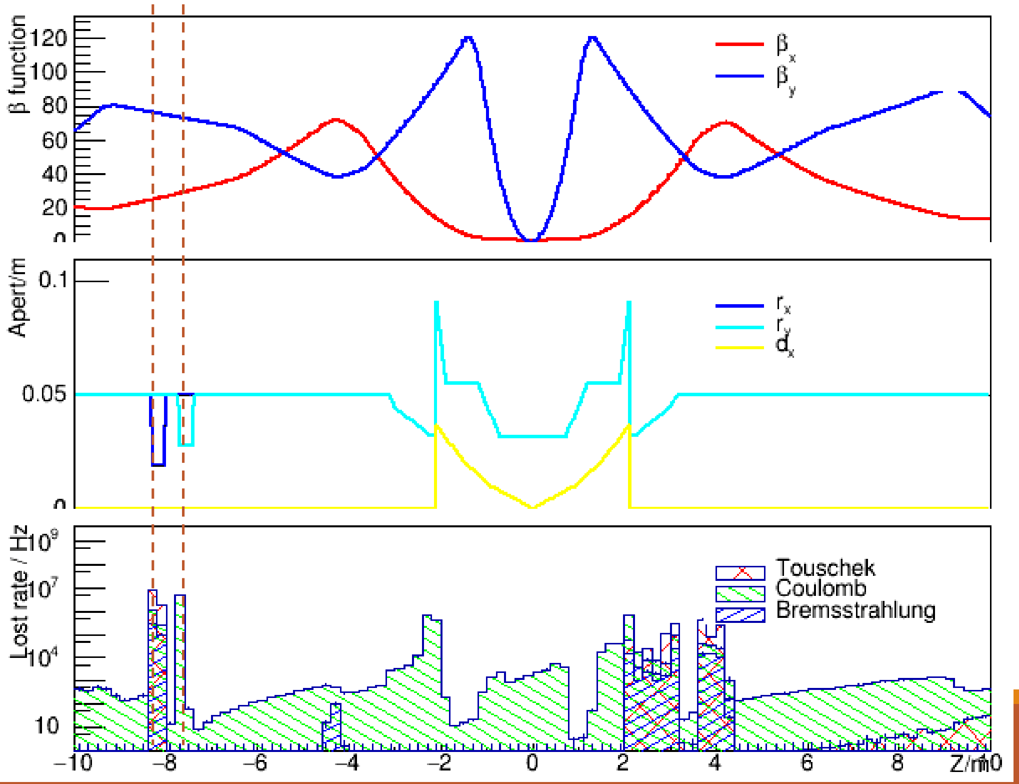


- ➢ 根据CAD设定Geant4 MDI几何：
- 束流管，磁铁，collimator，法兰
- 几何结构拓展至$\pm 10m$
- 主要是沿着束流管的物质
- 放入BOSS框架下模拟

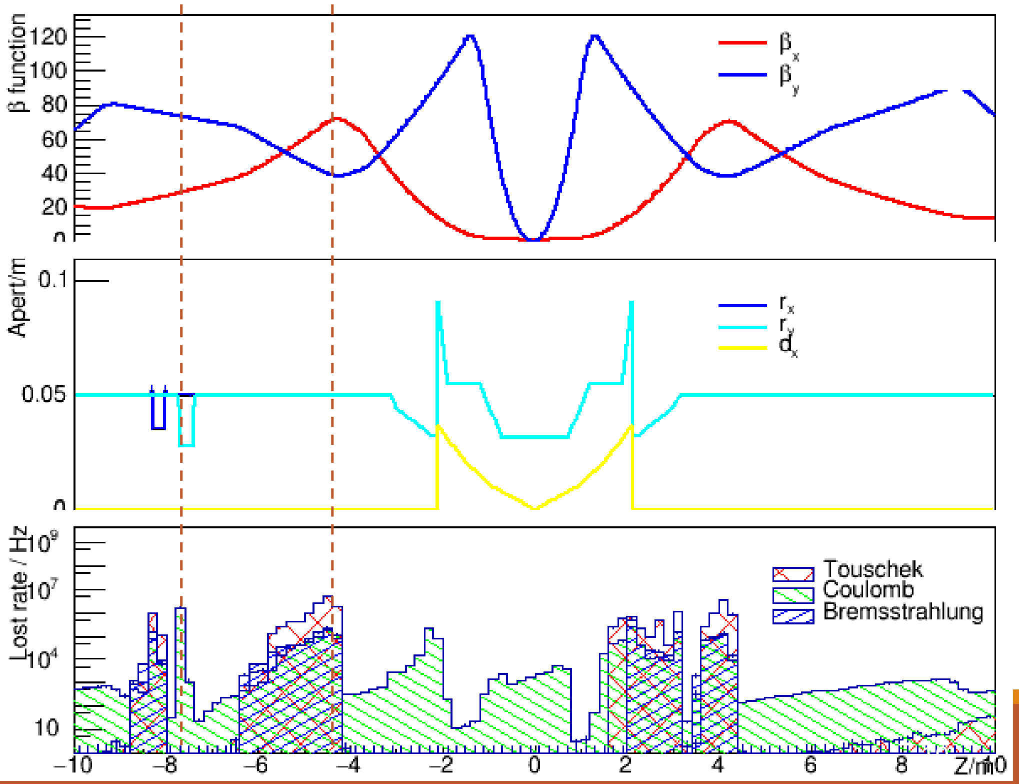
Adjustment of movable collimators

- ➢ 将所有movable collimator 孔径从19mm调整至35mm
- Touschek 丢失分布： collimator → β_x最大　　丢失率:下降86%
- Coulomb 丢失分布： 同collimator与Y形管处　　丢失率:下降77%

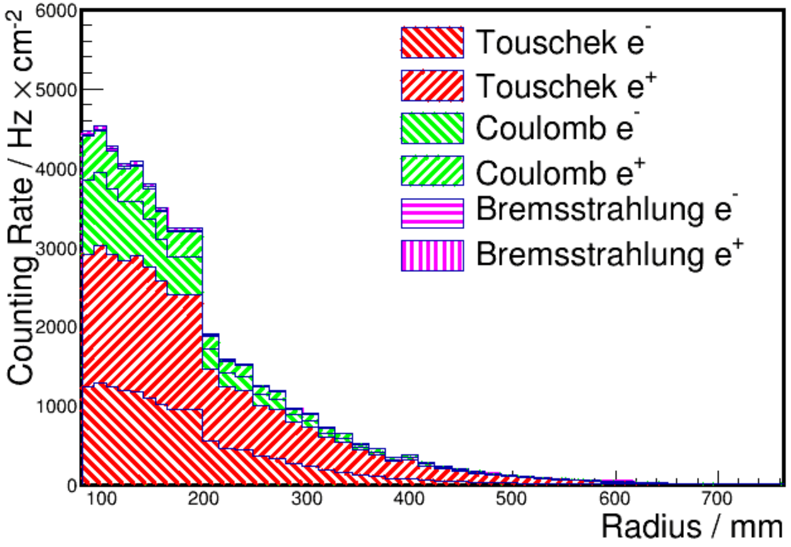
aperture=19mm

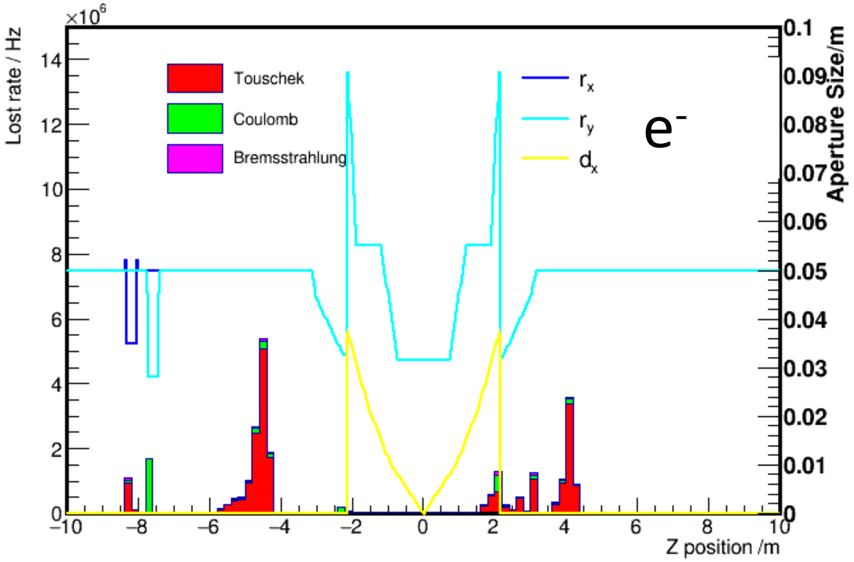


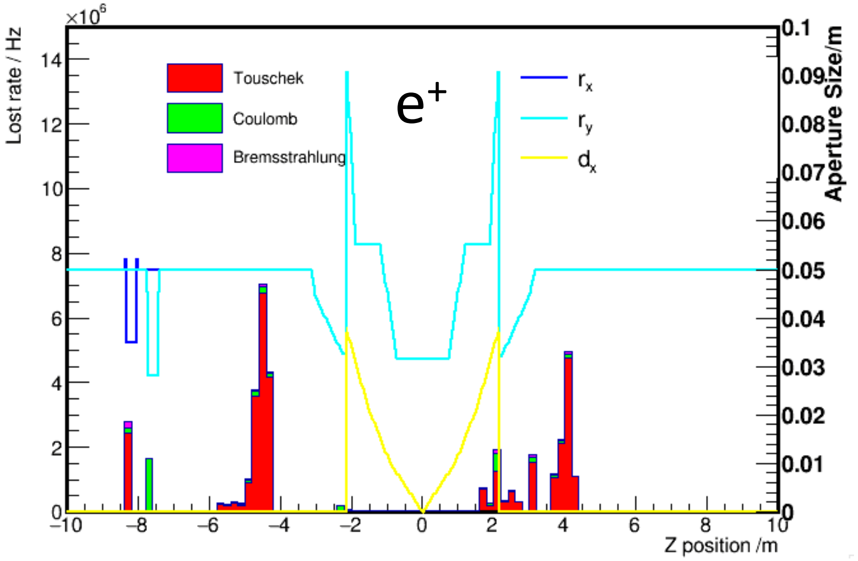
aperture=35mm



Lost position and count rate

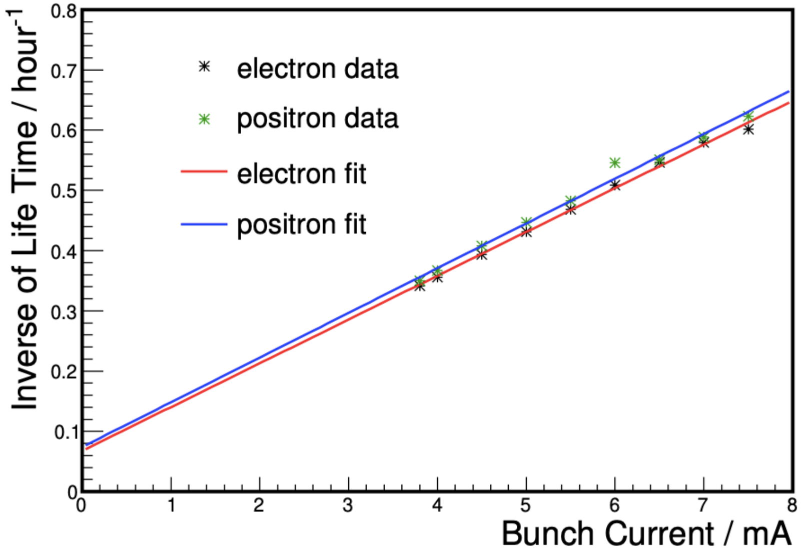






- 丢失率和计数率都是正电子比电子高～50%
- 模拟中电子环比正电子环多$\pm 11m$的collimator
- Touschek与Coulomb在$\pm 10m$内的丢失率占全环丢失的～20%

束流寿命与本底修正



正负电子寿命接近

Touschek 与 beam-gas寿命数据-MC比较

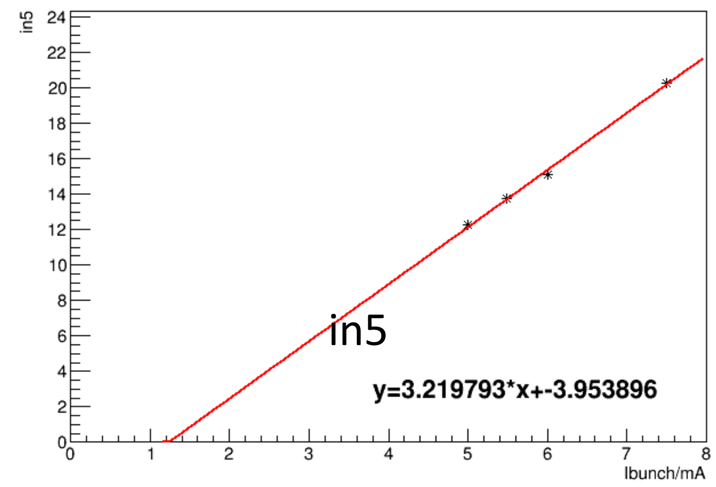
lifetime(hour)	e-	e+
data touschek	2.29	2.25
MC touschek	11.0	11.8
data beam-gas	13.5	14.8
MC beam-gas($P = 10^{-7} Pa$)	25.6	25.6

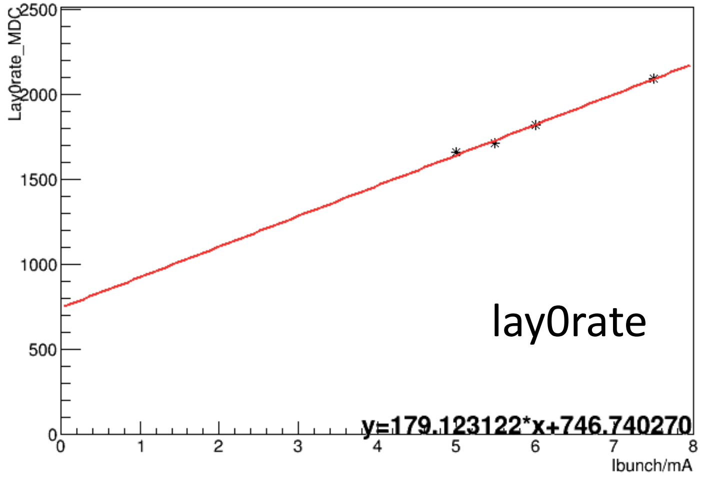
$\frac{1}{\tau}$将作为后续MC的修正因子

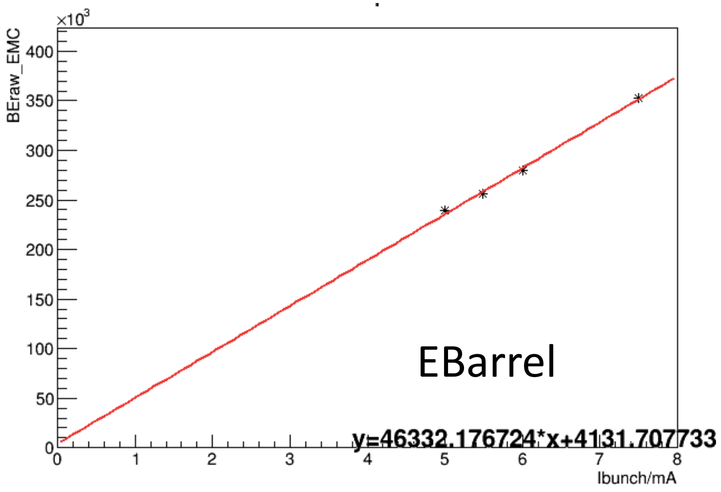
Touschek: S=4.8 for e-, 5.2 for e+

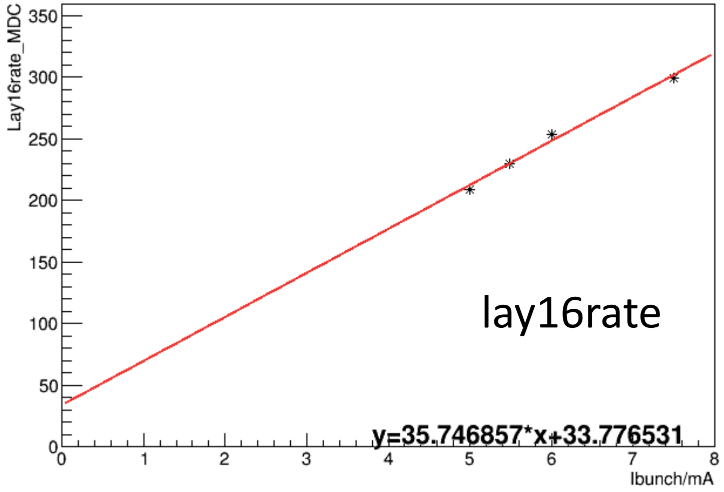
Beam-gas: S=2.8 for e-, 2.5 for e+

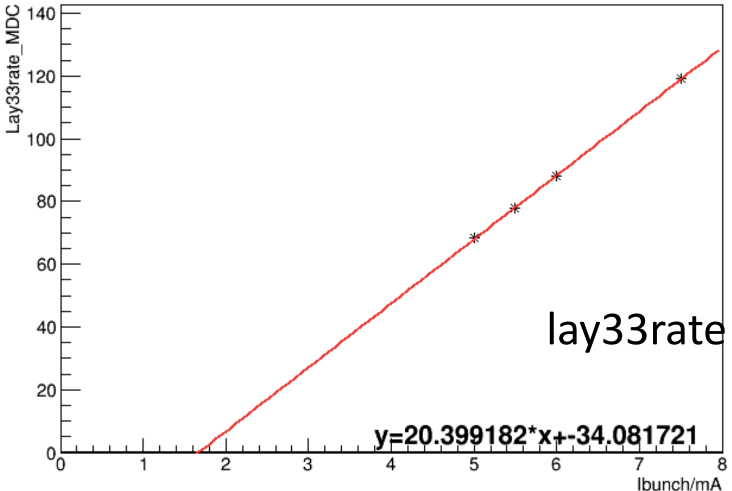
Touschek fit – Z=-8.2 m, DA=27 mm

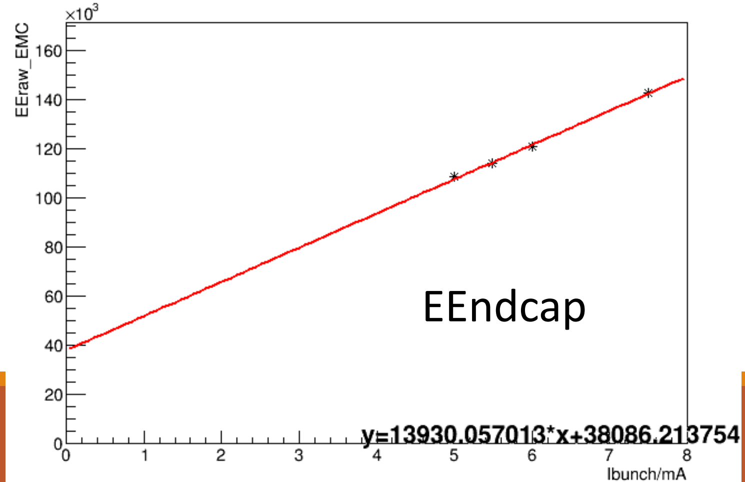












Touschek fit – Z=-8.2 m, DA=32 mm